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(54) Title: PROCESSES FOR THE PREPARATION OF 2-CHLORO-1,1,1,2,3,3,3-HEPTAFLUOROPROPANE, HEXAFLUORO-PROPENE AND 1,1,1,2,3,3,3-HEPTAFLUOROPROPANE

(57) Abstract: A process for the preparation of 2-chloro-1,1,1,3,3,3-heptafluoropropane is disclosed which involves (a) contacting a mixture comprising hydrogen fluoride, chlorine, and at least one starting material selected from the group consisting of halopropenes of the formula CX₃CCl=CX₂ and halopropanes of the formula the CX₃CClYCX₃, wherein each X is independently F or Cl, and Y is H, Cl or F (provided that the number of X and Y which are F totals no more than six) with a chlorofluorination catalyst in a reaction zone to produce a product mixture comprising CF₃CClFCF₃, HCl, HF, and underfluorinated halogenated hydrocarbon intermediates. The process is characterized by said chlorofluorination catalyst comprising at least one chromium-containing component selected from (i) a crystalline alpha-chromium oxide where at least 0.05 atom % of the chromium atoms in the alpha-chromium oxide lattice are replaced by nickel, trivalent cobalt or both nickel and trivalent cobalt, provided that no more than 2 atom % of the chromium atoms in the alpha-chromium oxide lattice are replaced by nickel and that the total amount of chromium atoms in the alpha-chromium oxide lattice that are replaced by nickel and trivalent cobalt is no more than 6 atom %, and (ii) a fluorinated crystalline oxide of (i). Also disclosed is a process for the manufacture of a mixture of HFC-227ea and hexafluoropropene by reacting a starting mixture comprising CFC-217ba and hydrogen in the vapor phase at an elevated temperature, optionally in the presence of a hydrogenation catalyst. This process involves preparing the CFC-217ba by the process described above.

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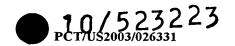
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TITLE

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PROCESSES FOR THE PREPARATION OF

2-CHLORO-1,1,1,2,3,3,3-HEPTAFLUOROPROPANE,

HEXAFLUOROPROPENE AND 1,1,1,2,3,3,3-HEPTAFLUOROPROPANE

FIELD OF THE INVENTION

The present invention relates to the synthesis of 2-chloro-1,1,1,2,3,3,3-heptafluoropropane and its integration into the manufacture of hexafluoriopropene and 1,1,1,2,3,3,3-heptafluoropropane.

BACKGROUND

The compound 2-chloro-1,1,1,2,3,3,3-heptafluoropropane ($CF_3CCIFCF_3$, CFC-217ba) is a useful intermediate for the preparation of hexafluoropropene (C_3F_6 , HFP), a valuable fluoromonomer, and 1,1,1,2,3,3,3-heptafluoropropane (CF_3CHFCF_3 , HFC-227ea), a fire extinguishant and propellant.

Commercial methods for the preparation of hexafluoropropene typically involve operating temperatures of greater than about 600°C. The high reaction temperatures lead to the formation of perfluoroisobutylene, an extremely toxic compound that is costly to remove and destroy (e.g., see European Patent Publication No. 002 098 B1). Processes for the manufacture of HFP at lower temperatures based on the use of acyclic three-carbon hydrocarbons or partially halogenated three-carbon hydrocarbons are disclosed in U.S. Patent No. 5,043,491, U.S. Patent No. 5,057,634 and U.S. Patent No. 5,068,472.

U.S. Patent No. 6,018,083 discloses a process for manufacture of HFP and HFC-227ea comprising (a) feeding CCl₂=CClCF₃, HF and Cl₂ to a first reaction zone containing a catalyst comprising trivalent chromium and operating at a temperature of at least 250°C but not more than 325°C to produce a reactor effluent comprising C₃Cl₃F₅, C₃Cl₂F₆ and CFC-217ba, HCl and HF; (b) distilling the reactor effluent of (a) to produce (i) a low boiling stream comprising HCl, (ii) a reactant stream comprising an azeotrope of CFC-217ba and HF and (iii) a high boiling stream comprising C₃Cl₃F₅ and C₃Cl₂F₆; (c) reacting the CFC-217ba of reactant stream (ii) with hydrogen in the presence of a catalyst to produce a mixture comprising HFP and HFC-227ea; (d) feeding the C₃Cl₃F₅ and C₃Cl₂F₆ of high-boiling stream (iii) along with HF to a second reaction zone containing a catalyst comprising trivalent chromium and operating at a temperature of at least about 375°C to produce a reaction product comprising CFC-217ba and HF; and (e) recycling the reaction product of (d) to the first reaction

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zone. U.S. Patent No. 3,865,885 discloses the catalytic chlorofluorination of CH_3CHFCH_3 to $CCl_2=CCICF_3$; WO PCT 99/51555 discloses processes for the purification and use of CFC-217ba (e.g., dehalogenation of CFC-217ba to make HFP or hydodechlorination of CFC-217ba to make HFC-227ea) and azeotropes of CFC-217ba with HF; and U.S, Patent No. 5,364,992 discloses the hydrogenolysis of halocarbons (e.g., CFC-217ba).

There remains a need for methods of manufacturing CFC-217ba.

SUMMARY OF THE INVENTION

This invention provides a process for the preparation of 2-chloro-1,1,1,3,3,3-heptafluoropropane. The process comprises (a) contacting a mixture comprising hydrogen fluoride (HF), chlorine (Cl₂), and at least one starting material selected from the group consisting of halopropenes of the formula CX₃CCl=CX₂ and halopropanes of the formula the CX₃CClYCX₃, wherein each X is independently selected from the group consisting of F and CI, and Y is selected from the group consisting of H, CI and F (provided that the number of X and Y which are F totals no more than six) with a chlorofluorination catalyst in a reaction zone to produce a product mixture comprising CF₃CClFCF₃, HCl, HF, and underfluorinated halogenated hydrocarbon intermediates. The process is characterized by said chlorofluorination catalyst comprising at least one chromiumcontaining component selected from (i) a crystalline alpha-chromium oxide where at least 0.05 atom % of the chromium atoms in the alpha-chromium oxide lattice are replaced by nickel, trivalent cobalt or both nickel and trivalent cobalt, provided that no more than 2 atom % of the chromium atoms in the alpha-chromium oxide lattice are replaced by nickel and that the total amount of chromium atoms in the alpha-chromium oxide lattice that are replaced by nickel and trivalent cobalt is no more than 6 atom %, and (ii) a fluorinated crystalline oxide of (i).

This invention also provides a process for the manufacture of a mixture of HFC-227ea and hexafluoropropene by reacting a starting mixture comprising CFC-217ba and hydrogen in the vapor phase at an elevated temperature, optionally in the presence of a hydrogenation catalyst. This process is characterized by preparing the CFC-217ba by the process described above.

DETAILED DESCRIPTION

In the chlorofluorination step of the process of this invention, one or more halopropene compounds having the formula $CX_3CCI=CX_2$ and halopropanes of the formula the $CX_3CCIYCX_3$ are typically reacted with

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chlorine (Cl₂) and substantially anhydrous hydrogen fluoride (HF). Suitable halopropene starting materials for the process of this invention $include \ CCl_3CCl=CCl_2 \ (HCP), \ CCl_2FCCl=CCl_2, \ CClF_2CCl=CCl_2,$ CF₃CCI=CCI₂ (CFC-1213xa), E- and Z-CF₃CCI=CCIF, and CF₃CCI=CF₂ (CFC-1215xc). HCP may be prepared by the reaction of 5 tetrachloroethene with chloroform in the presence of aluminum chloride to give 1,1,1,2,2,3,3-heptachloropropane which in turn is treated with base as described by Prins in Journal fuer Praktische Chemie, Volume 89, pages 414-424 (1914). CFC-1213xa may be prepared by chlorofluorination of isopropyl fluoride as disclosed in U. S. Patent 10 3,865,885. CFC-1215xc may be prepared by fluorination of CFC-1213xa in the presence of a chromium (III) oxide catalyst and a divalent zinc compound as disclosed in U. S. Patent No. 3,878,257. Suitable halopropane starting materials for the process of this invention include CF₃CCl₂CCl₃ (CFC-213ab), CF₃CCl₂CCl₂F (CFC-214ab), CF₃CHClCClF₂ (HCFC-225da) and CF₃CHClCF₃ (HCFC-226da). CFC-213ab and CFC-214ab may be prepared by chlorofluorination of propane or propylene as disclosed in U.S. Patent No. 5,057,634. HCFC-225da and HCFC-226da may be prepared by reaction of CFC-1213xa with HF and antimony pentachloride as described by McBee et al. in Journal of American 20 Chemical Society, Vol. 70, pages 2023-2024 (1948).

Preferably, the reaction of HF and Cl_2 with the halopropene(s) $\text{CX}_3\text{CCI=CX}_2$ and/or the halopropane(s) $\text{CX}_3\text{CCIYCX}_3$, is carried out in the vapor phase in a heated tubular reactor. A number of reactor configurations are possible including horizontal or vertical orientation of the reactor and different modes of contacting the halopropene starting materials with HF and chlorine.

In one embodiment of the invention, the starting halopropene(s) $CX_3CCI=CX_2$ and/or the halopropane(s) $CX_3CCIYCX_3$ may be initially vaporized and fed to the reactor as gas.

In another embodiment of the invention, the starting halopropene(s) $CX_3CCI=CX_2$ and/or the halopropane(s) $CX_3CCIYCX_3$ may be contacted with HF in a pre-reactor. The pre-reactor may be empty, but is preferably filled with a suitable packing such as $Monel^{TM}$ or HastelloyTM nickel alloy turnings or wool, or other material inert to HCl and HF which allows for efficient mixing of the $CX_3CCI=CX_2$ and/or $CX_3CCIYCX_3$ and the HF vapor.

Suitable temperatures for the pre-reactor are within the range of from about 80°C to about 250°C, preferably from about 100°C to about 200°C. For starting materials having fewer than three fluorine substituents, some substitution of chlorine substituents by fluorine may occur in the pre-reactor. Higher temperatures result in greater conversion of the halopropene(s) CX₃CCl=CX₂ and/or the halopropane(s) CX₃CClYCX₃ in the pre-reactor and a greater degree of fluorination in the converted products. Under these conditions, for example,

hexachloropropene is converted to a mixture containing predominantly

10 CFC-1213xa.

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The term "degree of fluorination" reflects the number of fluorine substituents that replace chlorine substituents in the CX3CCIYCX3 and CX₃CCI=CX₂ starting materials. For example, CF₃CCI=CCIF represents a higher degree of fluorination than CCIF2CCI=CCI2 and CF3CCI2CF3 represents a higher degree of fluorination than CCl₂FCCl₂CF₃. The term "underfluorinated halogenated hydrocarbon intermediates" means halopropanes of the formula CX3CCIYCX3 and halopropenes of the formula CX₃CCl=CX₂ wherein the number of X and Y which are F totals no more than six. Examples of underfluorinated intermediates are CCl₂=CCICCl₃, CCIF=CCICF₃, CCl₂=CCICCIF₂, CCl₂=CCICF₃, CF₂=CCICF₃, CCl₂=CCICCl₂F, CF₃CCl₂CCl₃, CF₃CCl₂CCl₂F, CF₃CHClCClF₂, and CF₃CHClCF₃ (i.e., the same compounds suitable as starting materials). Underfluorinated halgenated hydrocarbon intermediates may include unreacted starting material, but do not include either CFC-217ba (i.e., the desired product) or 1chloroheptafluoropropane (i.e., CFC-217ca).

The molar ratio of HF to the CX₃CCI=CX₂ and/or CX₃CCIYCX₃ starting material in the pre-reactor is typically from about the stoichiometric ratio of HF to halopropene to about 50:1. The stoichiometric ratio of HF to the starting material depends on whether the starting material is a halopropene or a halopropane, or a mixture, and the average degree of fluorination of the starting material fed to the pre-reactor. For example, if the halopropene is HCP and the desired final product is CFC-217ba, the stoichiometric ratio of HF to HCP is 7:1; if the halopropene is CFC-1213xa, the stoichiometric ratio of HF to CFC-1213xa is 4:1; and if the halopropane is CFC-214ab, the stoichiometric ratio of HF to CFC-214ab is 3:1. Preferably, the molar ratio of HF to starting material in the pre-reactor is from about twice the stoichiometric ratio of HF to halopropane or

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halopropene to about 40:1. Higher molar ratios of HF to starting material are not particularly beneficial. Lower ratios result in reduced yields of CFC-217ba unless additional HF is co-fed to the reaction zone.

If the starting materials are contacted with HF in a pre-reactor, the effluent from the pre-reactor is contacted with chlorine in the reaction zone of step (a).

In another embodiment of the invention, the starting material(s) may be contacted with Cl_2 in a pre-reactor, optionally in the presence of HF. The pre-reactor may be empty, but is preferably filled with a suitable packing such as MonelTM or HastelloyTM nickel alloy turnings or wool, activated carbon, or other material inert to HCl and Cl_2 which allows for efficient mixing of the $\text{CX}_3\text{CCIYCX}_3$ and/or $\text{CX}_3\text{CCI=CX}_2$ and the Cl_2 vapor.

Typically at least a portion of any halopropene starting material reacts with Cl₂ in the pre-reactor by addition to the olefinic bond to give a saturated halopropane. In addition, if HF is present, it may also react in the pre-reactor. Suitable temperatures for the pre-reactor in this embodiment of the invention are within the range of from about 80°C to about 250°C, preferably from about 100°C to about 200°C. Higher temperatures result in greater conversion of the halopropene starting material to saturated products and a greater degree of halogenation. In the presence of HF, the degree of fluorination will also increase at higher pre-reactor temperatures.

The term "degree of halogenation" reflects the total number of halogen substituents (chlorine plus fluorine) in a halopropane or halopropene product. For example, CF₃CCl₂CClF₂ has a higher degree of halogenation than CF₃CCl=CCl₂. Also, CF₃CClFCF₃ has a higher degree of halogenation than CF₃CHClCF₃.

The molar ratio of Cl₂ to starting material fed to either the prereactor or the reaction zone of step (a) is typically from about 1:1 to about 10:1, preferably from about 1:1 to about 5:1.

In a preferred embodiment of the invention, in the chlorfluorination step the starting materials are vaporized, preferably in the presence of HF, and contacted with HF and Cl_2 in a pre-reactor and then fed to a reaction zone. If the preferred amounts of HF and Cl_2 are fed in the pre-reactor, additional HF and Cl_2 are not required in the reaction zone. Suitable temperatures in the reaction zone are within the range of from about 280°C to not more than 450°C, preferably from about 300°C to about

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425°C. Higher temperatures result in greater conversion of the starting materials, but also contribute to reduced catalyst life. Lower temperatures than about 280°C result in yields of CFC-217ba often below 10%, and increased amounts of dichlorohexafluoropropane isomers. Nevertheless, the dichlorohexafluoropropane isomers may be subsequently separated from CFC-217ba and recycled back to the reaction zone.

Suitable reactor pressures for vapor phase embodiments of this invention may be in the range of from about 1 to about 30 atmospheres. Reactor pressures of about 5 atmospheres to about 30 atmospheres may be advantageously employed to facilitate separation of HCI from other reaction products in step (b) of the process.

The reaction zone of the chlorofluorination step of the process of the invention may contain a chlorofluorination catalyst comprising a crystalline metal-substituted alpha-chromium oxide where trivalent cobalt and/or nickel is substituted for chromium in the chromium oxide lattice. The amount of nickel should be no more than 2 atom % based on the lattice positions of the alpha-chromium oxide occupied by chromium (before substitution), and the amount of cobalt should be no more than 6 atom % based on the lattice positions of the alpha-chromium oxide occupied by chromium (before substitution). Also, the amount of cobalt, nickel, or both nickel and cobalt should occupy at least 0.05 atom %, but the total amount of cobalt and nickel together should occupy no more than 6 atom % based on the lattice positions of the alpha-chromium oxide occupied by chromium (before substitution). Accordingly, the metalsubstituted chromium oxides may be represented by the general formula $\alpha\text{-Ni}_x\text{Co}_y\text{Cr}_{2\text{-x-y}}\text{O}_3$ where x is from 0 to 0.04; y is from 0 to 0.12; x, y or each of x and y is at least 0.001; and x+y totals from 0.001 to 0.12. Crystalline oxides of this formula may be fluorinated before use in the reaction zone. Further information on the cobalt-substituted alphachromium oxides useful for this invention is provided in U.S. Patent Application 60/405,220 [CL2099 US PRV] filed August 22, 2002, and hereby incorporated by reference herein in its entirety. Further information on the nickel-substituted alpha-chromium oxides and mixed nickel- and cobalt- substituted alpha-chromium oxides useful for this invention is provided in U.S. Patent Application 60/405,221 [CL2100 US PRV] filed August 22, 2002, and hereby incorporated by reference herein in its entirety.

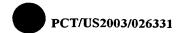
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These cobalt/nickel/chromium oxide compositions may be prepared by co-precipitation from aqueous solutions of the respective cobalt(II), cobalt(III), nickel(II), and chromium(III) salts. Preferably, the cobalt, nickel, and chromium salts are co-precipitated by adding ammonium hydroxide (aqueous ammonia) to an aqueous solution of soluble salts. The concentration of divalent or trivalent cobalt and/or the concentration of divalent nickel should be at least about 0.05 mole % of the total of cobalt, nickel, and chromium in the solution, provided that the concentration of divalent nickel should be no more than from about 2 mole % of the total of cobalt, nickel, and chromium in the solution and the total concentration of divalent or trivalent cobalt and divalent nickel should be no more than about 6 mole %. The solution should contain at least three moles of nitrate (i.e., NO₃-) per total mole of chromium (i.e., Cr³⁺). At least three moles of ammonium (i.e., NH₄+) per mole of chromium (i.e., Cr³⁺) should be added before the co-precipitated solid is collected. After precipitation is complete, water is evaporated from the mixture, and the resulting solid is dried and calcined as discussed in the two concurrently filed patent applications referenced above and incorporated herein by reference.

Of note are preparations where excess ammonium nitrate (i.e., more than three moles of ammonium nitrate per mole of chromium) is present in the aqueous solution. For example, in addition to the ammonium nitrate already present from reaction of ammonium hydroxide with chromium nitrate, from about 0.1 mole to about 7.0 moles of additional ammonium nitrate per mole of chromium may be added to the solution before, during, or after the co-precipitation of the compositions. The addition of excess ammonium nitrate to the precipitated mixture of cobalt, nickel, and chromium hydroxides prior to the dehydration step may be used to decrease the particle size of the formula α-Ni_xCo_yCr_{2-x-y}O₃ phase which in turn increases the surface area of that phase and the activity of the catalyst (see PREPARATION EXAMPLES 9 and 11 and EXAMPLES 9 and 10).

After the ammonium nitrate is added to the mixture, it is preferably stirred for about 0.5 to ten hours (more preferably one to five hours) at a temperature of from about 20°C to about 60°C. The mixture is then dried and calcined.

Other agents that serve this purpose include aqueous hydrogen peroxide (1% to 30% solutions), ozone, peroxy acids such as peroxyacetic acid, and ammonium persulfate. Agents such as halogens may be used,

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but are not preferred. Agents containing alkali metals such as potassium persulfate or sodium perborate may also be used but are not preferred.

After the precipitation of the mixture of cobalt, nickel, and chromium hydroxides is complete, and excess ammonium nitrate or other agents added if desired, the mixture is dried by evaporation.

Optionally, the precipitated mixture of cobalt, nickel, and chromium hydroxides may be collected and, if desired, washed with deionized water before drying. This may influence the activity of the catalyst (see PREPARATION EXAMPLES 7 and 8 and EXAMPLES 7 and 8).

After the cobalt, nickel, and chromium hydroxide mixture has been dried, the nitrate salts are then decomposed by heating the solid from about 250°C to about 350°C. The resulting solid is then calcined at temperature of from about 375°C to about 1000°C, preferably from about 400°C to about 600°C. Lower calcination temperatures may result in the presence of some residual nitrate impurities in the metal oxide. The calcination temperature can influence the activity of the catalysts and, in turn, the product distribution when the catalysts are used to change the fluorine distribution in hydrocarbons and halogenated hydrocarbons (see PREPARATION EXAMPLES 3, 4, 9, AND 10 and EXAMPLES 3, 4, 9, and 11).

The calcination is preferably carried out in the presence of oxygen, most preferably in the presence of air.

After calcination, the resulting metal-substituted crystallites are

typically not visually distinguishable from formula $\alpha\text{-Cr}_2O_3$ by transmission electron microscopy. Furthermore, X-ray and electron diffraction studies are typically entirely consistent with the formula $\alpha\text{-Cr}_2O_3$ structure with some lattice contraction proportional to the amount of Co(III) substituted for Cr(III) in the structure, and with some lattice expansion or contraction proportional to the amount of and Ni(II) and Ni(III), respectively, substituted for Cr(III) in the structure. Further details on the characterization of these compositions are provided in the two concurrently filed patent applications referenced above and incorporated herein by reference. The metal content of the chromium oxide compositions of the present invention effects the activity of the catalyst obtained after fluorinating the mixed metal oxide. For example, in the chlorofluorination of CCI₂=CCICF₃ to CF₃CCIFCF₃, the activity of the fluorinated metal oxide catalysts for formation of CF₃CCIFCF₃ at temperatures of about 400°C is improved for those compositions having

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nominally 1-3 atom % cobalt and/or up to 2 atom % nickel in the catalyst relative to a chromium oxide catalyst having no added metals (see TABLE 1).

TABLE 1

Activity of Fluorinated Metal-Substituted Chromium Oxides for Chlorofluorination of CCl₂=CClCF₃ to CF₃CClFCF₃ ^a

Nominal	Catalyst	Reactor	% CF ₃ CCIFCF ₃	
Cr/Co/Ni Ratio	Calcination	Temperature	in Product	
	Temperature			
100/0/0	400°C	400°C	24.1	
99/1/0	400°C	400°C, washed	47.4	
98/2/0	400°C	400°C	46.6	
98/2/0	550°C	400°C	36.7	
98/2/0	900°C	400°C	14.8 b	
98/0/2	400°C	375°C	27.4	
97/3/0	400°C	400°C, washed	31.7	
95/3/2	400°C	375°C, excess	34.0	
		NH ₄ NO ₃		

a. Catalysts were prepared by co-precipitation technique using ammonia. Molar feed ratios of HF, 1213xa, and Cl_2 = 30:1:2. The contact time is 15 seconds.

b. Molar feed ratios of HF, 1213xa, and $Cl_2 = 20:1:4$.

Nickel chromium spinel (nickel chromite, $NiCr_2O_4$) served as a catalyst for conversion of CFC-1213xa to CFC-215aa ($CF_3CCl_2CClF_2$) with good selectivity while cobalt chromium spinel (cobalt chromite, $CoCr_2O_4$) did not (see COMPARATIVE EXAMPLES 16 and 17).

The catalytic compositions employed in this invention may further comprise one or more additives in the form of metal compounds that alter the selectivity or activity of the crystalline metal-substituted alphachromium oxides or the fluorinated metal oxide catalysts containing chromium, cobalt, and/or nickel. Suitable additives may be selected from the group consisting of fluorides, oxides, or oxyfluoride compounds of Mg, Ca, Sc, Y, La, Ti, Zr, Hf, V, Nb, Ta, Mo, W, Mn, Re, Fe, Ru, Co, Rh, Ir, Ni, Pd, Pt, Cu, Ag, Au, Ce, and Zn.

The total content of the additive(s) in the compositions of the present invention may be from about 0.05 atom % to about 15 atom % based on the total metal content of the compositions. The additives may

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be incorporated into the compositions of the present invention by standard procedures such as the impregnation technique.

Generally, the calcined compositions will be pre-treated with a fluorinating agent prior to use as catalysts for changing the fluorine content of halogenated carbon compounds. Typically this fluorinating agent is HF though other materials may be used such as sulfur tetrafluoride, carbonyl fluoride, and fluorinated carbon compounds such as trichlorofluoromethane, dichlorodifluoromethane, chlorodifluoromethane, trifluoromethane, or 1,1,2-trichlorotrifluoroethane. This pretreatment can be accomplished, for example, by placing the catalyst in a suitable container which can be the reactor to be used to perform the process in the instant invention, and thereafter, passing HF over the dried, calcined catalyst so as to partially saturate the catalyst with HF. This is conveniently carried out by passing HF over the catalyst for a period of time, for example, about 0.1 to about 10 hours at a temperature of, for example, about 200°C to about 450°C.

Examples of compounds produced in step (a) of the process of this invention include CF₃CCIFCF₃ (CFC-217ba) and HCl in addition to underfluorinated halogenated propanes and propenes including CF₃CHCICF₃ (HCFC-226da), CF₃CCI₂CF₃ (CFC-216aa), CF₃CCIFCCIF₂ (CFC-216ba), CF₃CCI₂CCIF₂ (CFC-215aa), CF₃CCIFCCI₂F (CFC-215bb), CF₃CCI₂CCI₂F (CFC-214ab), and CF₃CCI=CF₂ (CFC-1215xc).

This process allows unreacted starting material and other underfluorinated intermediates to be recycled to the reactor for the production of additional CFC-217ba. For example the chlorofluorination step (step(a)) may be advantageously followed by a separation step (step (b)) separating the product of step (a) to recover CF₃CCIFCF₃ as a product and to obtain underfluorinated halogenated hydrocarbon intermediates; and a recycle step (step (c)) returning underfluorinated halogenated hydrocarbon intermediates obtained in step (b) back to the step (a) reaction zone.

In step (b) of the process of the invention, the effluent from the reaction zone in step (a) comprising CF₃CClFCF₃ (CFC-217ba), HCl, HF, and the underfluorinated halogenated propanes and propenes, is delivered to one or more separation zones in which CF₃CClFCF₃ with its azeotropic HF, is separated from the HCl, excess HF, and underfluorinated halogenated propanes and propenes. The separation zones may comprise conventional chemical processing equipment such

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as, but not limited to, scrubbers, decanters, and/or distillation columns. The CFC-217ba is recovered. The CFC-217ba/HF azeotrope as well as recovery of HF and CFC-217ba from said azeotrope is disclosed in International Patent Application WO 99/51555 the teachings of which are hereby incorporated by reference.

In step (c) of the process of this invention, underfluorinated halogenated propanes and propenes, as well as excess HF obtained in the separation zone(s) may be returned to step (a). Limited amounts of CFC-217ba and CFC-217ca may also be returned to the reaction zone.

The reaction zone and its associated feed lines, effluent lines, and associated units should be constructed of materials resistant to hydrogen fluoride and hydrogen chloride. Typical materials of construction, well-known to the fluorination art, include stainless steels, in particular of the austenitic type, the well-known high nickel alloys, such as MonelTM nickel-copper alloys, HastelloyTM nickel-based alloys and, InconelTM nickel-chromium alloys, and copper-clad steel.

The product of this invention, 2-chloro-1,1,1,2,3,3,3-heptafluoropropane (CFC-217ba), is useful as an intermediate for commercially valuable fluorocarbons. For example, hydrodechlorination of CFC-217ba gives either hexafluoropropene, a useful polymer intermediate, or 1,1,1,2,3,3,3-heptafluoropropane (HFC-227ea), which finds application as a propellant and fire extinguishant. Fluorination of CFC-217ba gives octafluoropropane (FC-218) which is useful as an etchant in the electronics industry.

The use of CFC-217ba as a starting material for reaction with H₂ is well known. For example, CFC-217ba can be converted to a product comprising HFC-227ea and HFP by contacting the CFC-217ba with hydrogen at an elevated temperature in the vapor phase over a catalyst comprising at least one metal selected from the group consisting of rhenium, ruthenium, rhodium and palladium. The reaction temperature for these metal containing catalysts is at least about 100°C. Further details and other methods of hydrodechlorination of CFC-217ba are described in U.S. Patent No. 6,018,083. CFC-217ba can also be converted to a product comprising HFC-227ea and HFP by contacting the CFC-217ba with hydrogen at an elevated temperature in an empty reaction vessel of nickel, iron or their alloys at a pressure of from 0 to 69 atmospheres and a temperature of from 350°C to 700°C as disclosed on U.S. Patent No. 5,364,992.

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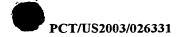
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Without further elaboration, it is believed that one skilled in the art can, using the description herein, utilize the present invention to its fullest extent. The following specific embodiments are, therefore, to be construed as merely illustrative, and do not constrain the remainder of the disclosure in any way whatsoever.

EXAMPLES

Catalyst Preparation

COMPARATIVE PREPARATION EXAMPLE 1

Preparation of 100% Chromium Catalyst (400°C)

A solution of 400 g $Cr(NO_3)_3[9(H_2O)]$ (1.0 mole) in 1000 mL of deionized water was treated dropwise with 477 mL of 7.4M aqueous ammonia raising the pH to about 8.5. The slurry was stirred at room temperature overnight. After re-adjusting the pH to 8.5 with ammonia, the mixture was poured into evaporating dishes and dried in air at 120°C. The resulting solid was then calcined in air at 400°C for 24 hours.

PREPARATION EXAMPLE 2

Preparation of 99%Chromium/1%Cobalt Catalyst (washed; 400°C) A solution of 792.29 g Cr(NO₃)₃[9(H₂O)] (1.98 moles) and 5.82 g Co(NO₃)₂[6(H₂O)] (0.0200 mole) was prepared in 2000 mL of deionized water. The solution was treated dropwise with 955 mL of 7.4M aqueous ammonia which raised the pH to about 8.5. The slurry was stirred at room temperature overnight. The pH was adjusted to 8.5 the following day. The solid was then collected using two fritted funnels; the resulting solid in each funnel was washed with 15-20 liters of deionized water. The solids were dried in air at 120°C for 24 hours and then calcined in air at 400°C for 24 hours.

PREPARATION EXAMPLE 3

Preparation of 98%Chromium/2%Cobalt Catalyst (400°C) A solution of 784.30 g $Cr(NO_3)_3[9(H_2O)]$ (1.96 moles) and 11.64 g $Co(NO_3)_2[6(H_2O)]$ (0.040 mole) was prepared in 2000 mL of deionized water. The solution was treated dropwise with 950 mL of 7.4M aqueous ammonia which raised the pH from about 1.8 to about 8.5. The slurry was stirred at room temperature overnight and then evaporated to dryness in air at 110-120°C for 48 hours. The dried catalyst was divided in half. One half was calcined in air at 400°C for 24 hours.

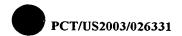
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PREPARATION EXAMPLE 4

Preparation of 98%Chromium/2%Cobalt Catalyst (900°C)

The other half of the dried catalyst prepared in PREPARATION

EXAMPLE 3 was calcined in air at 900°C for 24 hours.

PREPARATION EXAMPLE 5

Preparation of 98%Chromium/2%Cobalt Catalyst (550°C)

A solution of 1,010 g $Cr(NO_3)_3[9(H_2O)]$ (2.52 moles) and 14.6 g $Co(NO_3)_2[6(H_2O)]$ (0.050 mole) was prepared in 1000 mL of deionized water. The green solution was evaporated at a temperature of about 100°C until a thick, black precipitate formed. The solid was dried at 300-325°C on a hot plate. The solid was then transferred to a porcelain dish and calcined in a furnace at 550°C for 20 hours.

PREPARATION EXAMPLE 6

Preparation of 98%Chromium/2%Cobalt Catalyst (550°C)

A solution of 1,010 g $Cr(NO_3)_3[9(H_2O)]$ (2.52 moles) and 14.6 g $Co(NO_3)_2[6(H_2O)]$ (0.0502 mole) was prepared in 1500 mL of deionized water. The solution was treated with 500 mL of 29 weight percent aqueous ammonia with mixing provided by a mechanical stirrer. The mixture was stirred for two hours and the pH stabilized at 6.0. The mixture was transferred to a large, ceramic dish. Water was driven off by heating. After most of the water had evaporated, the sample was heated to 250-300°C on a hot plate. The resulting solid was then transferred to a porcelain dish and calcined in a furnace at 550°C for 20 hours.

PREPARATION EXAMPLE 7

Preparation of 97%Chromium/3%Cobalt Catalyst (unwashed; 400°C) A solution of 776.29 g Cr(NO₃)₃[9(H₂O)] (1.94 moles) and 17.46 g Co(NO₃)₂[6(H₂O)] (0.060 mole) was prepared in 2000 mL of deionized water. The solution was treated dropwise with 950 mL of 7.4M aqueous ammonia until the pH reached about 8.5. The slurry was stirred at room temperature for 24 hours and then evaporated to dryness in air at 110-120°C. The dried catalyst was ground to a powder and then calcined in air at 400°C for 24 hours.

PREPARATION EXAMPLE 8

Preparation of 97%Chromium/3%Cobalt Catalyst (washed; 400°C) A solution of 776.29 g Cr(NO₃)₃[9(H₂O)] (1.94 moles) and 17.46 g $Co(NO_3)_2[6(H_2O)]$ (0.060 mole) was prepared in 2000 mL of deionized water. The solution was treated dropwise with 955 mL of 7.4M aqueous ammonia which raised the pH to about 8.5. The slurry was stirred at room

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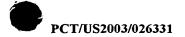
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temperature overnight and the pH adjusted to 8.5 the following day. The solid was collected in two 3 L fritted funnels and each portion washed with 15-20 L of deionized water. The washed solid was then evaporated to dryness in air at 120°C for 24 hours and then calcined in air at 400°C for 24 hours.

PREPARATION EXAMPLE 9

Preparation of 95%Chromium/5%Cobalt Catalyst (400°C)
A solution of 760.28 g Cr(NO₃)₃[9(H₂O)] (1.90 moles) and 29.10 g
Co(NO₃)₂[6(H₂O)] (0.10 mole) was prepared in 2000 mL of deionized
water. The solution was treated dropwise with 950 mL of 7.4M aqueous
ammonia which raised the pH to about 8.5. The slurry was stirred at room
temperature overnight and then evaporated to dryness in air at 110-120°C
for 48 hours. The dried catalyst was divided in half. One half was
calcined in air at 400°C for 24 hours.

PREPARATION EXAMPLE 10

Preparation of 95%Chromium/5%Cobalt Catalyst (900°C)

The other half of the dried catalyst prepared in PREPARATION

EXAMPLE 9 was calcined in air at 900°C for 24 hours.

PREPARATION EXAMPLE 11

Preparation of 95%Chromium/5%Cobalt Catalyst (1.6 eq. of excess NH₄NO₃; 400°C)

A solution of 760.28 g Cr(NO₃)₃[9(H₂O)] (1.90 moles) and 29.10 g $Co(NO_3)_2[6(H_2O)]$ (0.10 mole) was prepared in 2000 mL of deionized water. The solution was treated dropwise with 950 mL of 7.4M aqueous ammonia; the pH reached 8.5. The slurry was stirred at room temperature for 24 hours and then treated with a solution of 240.12 g NH₄NO₃ (3.0 moles). After stirring at room temperature for 2 hours, the mixture was evaporated to dryness in air at 120°C and held at that temperature over the weekend. The dried catalyst was ground to a powder with a mortar and pestle and then calcined in air at 400°C for 24 hours.

PREPARATION EXAMPLE 12

Preparation of 90%Chromium/10%Cobalt Catalyst (washed; 400°C) A solution of 720.27 g Cr(NO₃)₃[9(H₂O)] (1.80 moles) and 58.21 g Co(NO₃)₂[6(H₂O)] (0.20 mole) was prepared in 2000 mL of deionized water. The solution was treated dropwise with 955 mL of 7.4M aqueous ammonia which raised the pH from about 2.1 to about 8.5. The slurry was stirred at room temperature overnight. The following day, the pH was the increased from 8.05 to 8.5 by addition of aqueous ammonia. The solid

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was collected in two 3 L fritted funnels and each portion washed with 15-20 L of deionized water. The washed solid was then evaporated to dryness in air at 120°C for 24 hours. The dried catalyst was then calcined in air at 400°C for 24 hours.

PREPARATION EXAMPLE 13

Preparation of 90%Chromium/10%Cobalt Catalyst (3.3 eq. of excess NH₄NO₃; 400°C)

A solution of 72.03 g Cr(NO₃)₃[9(H₂O)] (0.18 mole) and 5.82 g Co(NO₃)₂[6(H₂O)] (0.020 mole) was prepared in 200 mL of deionized water. The solution was brought to pH 8.5 treatment with 7.4M aqueous ammonia. The slurry was stirred at room temperature for 24 hours. The mixture was then treated with a solution of 48.02 g of NH₄NO₃ (0.60 mole) dissolved in 100 mL of water. The slurry was stirred for one hour and then dried at 120°C in air for about 90 hours. The dried solid was crushed to a powder and then placed in covered dish and calcined at 400°C for 24 hours in air.

PREPARATION EXAMPLE 14

Preparation of 90%Chromium/10%Cobalt Catalyst (6.7 eq. of excess NH₄NO₃; 400°C)

PREPARATION EXAMPLE 13 was repeated except that the mixture of chromium/cobalt oxide/hydroxides was treated with a solution of 96.05 g of NH₄(NO₃) (1.2 moles) dissolved in 200 mL of water.

PREPARATION EXAMPLE 15

Preparation of 98%Chromium/2%Nickel Catalyst (400°C)

A solution of 588.3 g $Cr(NO_3)_3[9(H_2O)]$ (1.47 moles) and 8.72 g (0.030 mole) $Ni(NO_3)_2[6(H_2O)]$ dissolved in 1.5 L of deionized water was treated with 7.4M aqueous ammonia until the pH reached 8.5.. The addition of ammonia took 1.5 hours. The slurry was stirred at room temperature for 24 hours; ammonia was added occasionally to keep the pH at about 8.5. The mixture was then evaporated to dryness in air at 110°C over the course of 40 hours. The dried catalyst was ground to a powder and then calcined in air at 400°C for 24 hours.

PREPARATION EXAMPLE 16

Preparation of 95%Chromium/5%Nickel Catalyst (400°C)

The procedure of PREPARATION EXAMPLE 8 was repeated using a solution of 760.3 g Cr(NO₃)₃[9(H₂O)] (1.90 moles) and 29.08 g (0.10 mole) Ni(NO₃)₂[6(H₂O)] dissolved in 2 L of deionized water. After the

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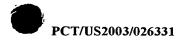
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addition of ammonia and evaporation at 110°C, the solid was calcined in air at 400°C for 24 hours.

PREPARATION EXAMPLE 17

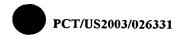
Preparation of 95%Chromium/3%Cobalt/2% Nickel Catalyst (6.2 eq. of excess NH₄NO₃; 400°C)

A solution of 380.14 g Cr(NO₃)₃[9(H₂O)] (0.95 mole), 8.73 g Co(NO₃)₂[6(H₂O)] (0.030 mole), and 5.82 g Ni(NO₃)₂[6(H₂O)] (0.020 mole) was prepared in 1000 mL of deionized water. The solution pH was increased from 3.1 to 8.5 by treatment with 7.4M aqueous ammonia. The slurry was stirred at room temperature for 21 hours at pH 8.5. The mixture was then treated with a solution of 472.24 g of NH₄(NO₃) (5.90 moles) dissolved in 500 mL of water. The slurry was stirred for one hour at room temperature and then dried at $110-120^{\circ}$ C in air for about 96 hours. The dried solid was crushed to a powder and then placed in covered crucible and calcined at 400° C for 24 hours in air.

General Procedure for Chlorofluorination Reactions

The following general procedure was followed in the chlorofluorination of CFC-1213xa using the catalysts prepared as described above.

A weighed quantity of a calcined chromium oxide composition was placed in a was placed in a 5/8" (1.58 cm) diameter Inconel[™] nickel alloy reactor tube heated in a fluidized sand bath. The tube was then heated from about 170°C to about 200°C in a flow of nitrogen (50 cc/min, 8.3×10⁻⁷ m³/s) over 0.5 hour to 2 hours. HF and nitrogen were then cofed to the reactor at flow rates of 50 cc/min (8.3×10-7 m³/s) each at 175°C. After 0.5 to 2 hours, the HF and nitrogen flow rates were adjusted to 80 cc/min $(1.3\times10^{-6} \text{ m}^3/\text{s})$ and 20 cc/min $(3.3\times10^{-7} \text{ m}^3/\text{s})$, respectively, and the temperature of the reactor increased to 400-410°C over a period of 3 to 5 hours. The HF flow was then stopped and the reactor purged with nitrogen at about 300°C. CFC-1213xa was fed from a pump to a vaporizer maintained at about 118°C. The 1213xa vapor was combined with the appropriate molar ratios of HF and chlorine in a 1/2" (1.27 cm) diameter Monel[™] nickel alloy tube packed with Monel[™] turnings. The mixture of reactants then entered the reactor; the contact time in the reactor was typically 15 seconds. All reactions were conducted at a nominal pressure of one atmosphere.



General Procedure for Fluorocarbon Product Analysis

The following general procedure is illustrative of the method used for analyzing the products of fluorocarbon reactions. Part of the total reactor effluent was sampled on-line for organic product analysis using a gas chromatograph equipped with a mass selective detector (GC-MS). The gas chromatography was accomplished with a 20 ft. (6.1 m) long x 1/8 in. (0.32 cm) diameter tubing containing Krytox[®] perfluorinated polyether on an inert carbon support. The helium flow was 30 mL/min $(5.0\times10^{-7} \text{ m}^3\text{/s})$. Gas chromatographic conditions were 60°C for an initial hold period of three minutes followed by temperature programming to 200°C at a rate of 6°C/minute.

The bulk of the reactor effluent containing organic products and also inorganic acids such as HCI and HF was treated with aqueous caustic prior to disposal.

15 **LEGEND**

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13 is CCIF₃

113 is CCI₂FCCIF₂

114a is CF₃CCl₂F

214ab is CCI₂FCI₂CF₃

215bb is CCI₂FCCIFCF₃

216aa is CF₃CCI₂CF₃

217ba is CF₃CCIFCF₃

218 is C₃F₈

226da is CF₃CHCICF₃

1214 is C₃CI₂F₄

1225 is C₃HF₅

CT is contact time

112 is CCI₂FCCI₂F
114 is CCIF₂CCIF₂
115 is CF₃CCIF₂
215aa is CCIF₂CCI₂CF₃
216cb is CF₃CF₂CCIF₂
216ba is CCIF₂CCIFCF₃
217ca is CF₃CF₂CCIF₂
225da is CF₃CHCICCIF₂
1213xa is CCI₂=CCICF₃
1215xc is CF₂=CCICF₃

COMPARATIVE EXAMPLE 1

100% Chromium(III) oxide (calcined at 400°C, 27.8 g, 20 mL, -12 to +20 mesh, (1.68 to 0.84 mm)), prepared as described in COMPARATIVE PREPARATION EXAMPLE 1 was placed in a 5/8" (1.58 cm) diameter Inconel[™] nickel alloy reactor tube heated in a fluidized sand bath. The chromium oxide was purged with nitrogen and fluorinated following the general procedure. Chlorofluorination of CFC-1213xa began at 300°C with HF, CFC-1213xa, and chlorine vapor co-fed to the reactor at a contact time of 15 seconds. The GC-MS analyses of the reactor effluent



at 300°C, 375°C, and 400°C with molar feed ratios of 20:1:4 and 30:1:2 are given in Table 2.

EXAMPLE 2

Cobalt-substituted chromium oxide (Cr/Co 99/1, 29.0 g, 20 mL, -12 to +20 mesh, (1.68 to 0.84 mm)), prepared as described in PREPARATION EXAMPLE 2, was placed in a 5/8" (1.58 cm) diameter Inconel[™] nickel alloy reactor tube heated in a fluidized sand bath. The cobalt chromium oxide was purged with nitrogen and fluorinated following the general procedure. Chlorofluorination of CFC-1213xa began at 300°C with HF, CFC-1213xa, and chlorine co-fed to the reactor at a contact time was 15 seconds. The GC-MS analyses of the reactor effluent at 300°C, 350°C, and 400°C with molar feed ratios of 20:1:4 and 30:1:2 are given in Table 2.

EXAMPLE 3

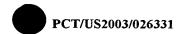
Cobalt-substituted chromium oxide (Cr/Co 98/2, calcined at 400°C, 15 21.06 g, 15 mL, -12 to +20 mesh, (1.68 to 0.84 mm)), prepared as described in PREPARATION EXAMPLE 3, was placed in a 5/8" (1.58 cm) diameter Inconel[™] nickel alloy reactor tube heated in a fluidized sand bath. The cobalt chromium oxide was heated from 77°C to 176°C in a flow of nitrogen (50 cc/min, 8.3×10^{-7} m³/s) over the course of about 1.7 hours. 20 HF and N₂ were then co-fed to the reactor at a flow rate of 50 cc/min (8.3×10⁻⁷ m³/s) each. After 1 hour the temperature was then increased to 326°C over 3 hours while maintaining the HF and N₂ flows at 50 cc/min $(8.3\times10^{-7} \text{ m}^3\text{/s})$. The N₂ and HF flows were then adjusted to 25 cc/min $(4.2\times10^{-7} \text{ m}^3\text{/s})$ and 50 cc/min $(8.3\times10^{-7} \text{ m}^3\text{/s})$, respectively, while the 25 reactor temperature was increased to 401°C over 1 hour. The N₂ and HF flows were then adjusted to 10 cc/min (1.7×10⁻⁷ m³/s) and 50 cc/min (8.3×10⁻⁷ m³/s), respectively, while the reactor temperature was maintained at 401°C for 1 hour. At the end of this period, the HF flow was stopped and the reactor cooled to 280°C under 20 sccm (3.3×10⁻⁷ m³/s) 30 nitrogen flow. Chlorofluorination of CFC-1213xa began at 280°C with HF, CFC-1213xa, and chlorine vapor co-fed to the reactor at a contact time of 15 seconds. The GC-MS analyses of the reactor effluent at 300°C, 350°C, and 400°C with molar feed ratios of 20:1:4 and 30:1:2 are given in 35 Table 2.

EXAMPLE 4

Cobalt-substituted chromium oxide (Cr/Co 98/2, calcined at 900°C, 27.52 g, 15 mL, -12 to +20 mesh, (1.68 to 0.84 mm)), prepared as

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described in PREPARATION EXAMPLE 4, was placed in a 5/8" (1.58 cm) diameter Inconel ™ nickel alloy reactor tube heated in a fluidized sand bath. The cobalt chromium oxide was purged with nitrogen and fluorinated following the general procedure. Chlorofluorination of CFC-1213xa began at 300°C with HF, CFC-1213xa, and chlorine vapor co-fed to the reactor at a contact time of 15 seconds. The GC-MS analyses of the reactor effluent at 300°C and 400°C with a molar feed ratio of 20:1:4 are given in Table 2.

EXAMPLE 5

Cobalt-substituted chromium oxide (Cr/Co 98/2, calcined at 550°C, -10 - 32.0 g, 20 mL, -12 to +20 mesh, (1.68 to 0.84 mm)), prepared as described in PREPARATION EXAMPLE 5, was placed in a 5/8" (1.58 cm) diameter Inconel[™] nickel alloy reactor tube heated in a fluidized sand bath. The cobalt chromium oxide was heated from 65°C to 176°C in a flow of nitrogen (50 cc/min, 8.3×10⁻⁷ m³/s) over the course of about 0.8 hour. HF and N₂ were then co-fed to the reactor at flow rates of 50 cc/min 15 $(8.3\times10^{-7} \text{ m}^3\text{/s})$ each. After 0.6 hour the N₂ and HF flows were then adjusted to 20 cc/min (3.3×10⁻⁷ m³/s) and 80 cc/min (1.3×10⁻⁶ m³/s), respectively while the reactor temperature was increased to 411°C over 3 hours. The catalyst was held at 411°C for 0.75 hour. The N₂ and HF flows were then adjusted to 10 cc/min (1.7×10⁻⁷ m³/s) and 50 cc/min 20 (8.3×10⁻⁷ m³/s), respectively, while the reactor temperature was maintained at 411°C for an additional 2 hours. At the end of this period, the HF flow was stopped and the reactor cooled to 295°C under 15 sccm (2.5×10-7 m³/s) nitrogen flow. Hydrogen fluoride, CFC-1213xa, and chlorine were then co-fed to the reactor with a contact time of 15 seconds. 25 The GC-MS analyses of the reactor effluent at 300°C, 350°C, and 400°C with molar feed ratios of 20:1:4 and 30:1:2 are given in Table 2.

EXAMPLE 6

Cobalt-substituted chromium oxide (Cr/Co 98/2, calcined at 550°C, 29.4 g, 20 mL, -12 to +20 mesh, (1.68 to 0.84 mm)), prepared as described in PREPARATION EXAMPLE 6, was placed in a 5/8" (1.58 cm) diameter Inconel[™] nickel alloy reactor tube heated in a fluidized sand bath. The cobalt chromium oxide was purged with nitrogen and fluorinated following the general procedure. Hydrogen fluoride, CFC-1213xa, and chlorine were then co-fed to the reactor at a contact time of 15 seconds. The GC-MS analyses of the reactor effluent at 300°C, 350°C, and 400°C with molar feed ratios of 20:1:4 and 30:1:2 are given in Table 2.

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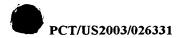
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EXAMPLE 7

Cobalt-substituted chromium oxide (Cr/Co 97/3, 31.6 g, 20 mL, -12 to +20 mesh, (1.68 to 0.84 mm)), prepared as described in PREPARATION EXAMPLE 8 was placed in a 5/8" (1.58 cm) diameter Inconel[™] nickel alloy reactor tube heated in a fluidized sand bath. The cobalt chromium oxide was purged with nitrogen and fluorinated following the general procedure. Chlorofluorination of CFC-1213xa began at 300°C with HF, CFC-1213xa, and chlorine vapor co-fed to the reactor at a contact time of 15 seconds. The GC-MS analyses of the reactor effluent at 300°C, 350°C, and 400°C with molar feed ratios of 20:1:4 and 30:1:2 are given in Table 2.

EXAMPLE 8

Cobalt-substituted chromium oxide (Cr/Co 97/3, 28.2 g, 20 mL, -12 to +20 mesh, (1.68 to 0.84 mm)), prepared as described in PREPARATION EXAMPLE 7 was placed in a 5/8" (1.58 cm) diameter Inconel[™] nickel alloy reactor tube heated in a fluidized sand bath. The cobalt chromium oxide was purged with 25 cc/min (4.2×10⁻⁷ m³/s) nitrogen at 150C for 16 hours. The N₂ flow was increased to 50 cc/min $(8.3\times10^{-7} \text{ m}^3\text{/s})$ at 175C for 0.5 hour. N₂ and HF were then co-fed to the reactor at flow rates of 50 cc/min (8.3×10-7 m³/s) each. After 1.2 h, the nitrogen flow was decreased to 20 cc/min (3.3×10⁻⁷ m³/s) and the HF flow increased to 80 cc/min (1.3×10⁻⁶ m³/s). The reactor temperature was gradually increased to 300°C over a 5.7 hours period. The HF was turned off and the reactor purged with 20 cc/min (3.3×10⁻⁷ m³/s) nitrogen for about 16 hours at 300°C. The flows of N₂ and HF were then established at 20 cc/min $(3.3 \times 10^{-7} \text{ m}^3/\text{s})$ and 80 cc/min $(1.3 \times 10^{-6} \text{ m}^3/\text{s})$, respectively, and the reactor temperature increased from 298°C to 410°C over 3.5 hours and then held at 410°C for 2.3 hours. At the end of this period, the HF flow was stopped and the reactor cooled to 300°C under 20 sccm (3.3×10⁻⁷ m³/s) nitrogen flow. Chlorofluorination of CFC-1213xa began at 300°C with HF, CFC-1213xa, and chlorine vapor co-fed to the reactor at a contact time of 15 seconds. The GC-MS analyses of the reactor effluent at 300°C and 350°C with molar feed ratios of 20:1:4 and 30:1:2 are given in Table 2.

EXAMPLE 9

Cobalt-substituted chromium oxide (Cr/Co 95/5, 21.8 g, 15 mL, -12 to +20 mesh, (1.68 to 0.84 mm)), prepared as described in PREPARATION EXAMPLE 9 was placed in a 5/8" (1.58 cm) diameter

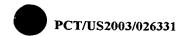
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Inconel[™] nickel alloy reactor tube heated in a fluidized sand bath. The cobalt chromium oxide was heated from 52°C to 173°C in a flow of nitrogen (50 cc/min, 8.3×10⁻⁷ m³/s) over the course of about 1 hour. HF and nitrogen were then co-fed to the reactor at flow rates of 25 cc/min $(4.2 \times 10^{-7} \text{ m}^3/\text{s})$ and 75 cc/min $(1.25 \times 10^{-6} \text{ m}^3/\text{s})$, respectively. After 2.2 hours, the nitrogen and HF flow rates were adjusted to 50 cc/min (8.3×10⁻⁷ m³/s) each and the reactor temperature was gradually increased to 299°C over 3 hours. The reactor was purged with 20 cc/min (3.3×10-7 m³/s) nitrogen overnight at 299°C. HF and nitrogen were then co-fed to the reactor at 80 cc/min (1.3×10⁻⁶ m³/s) and 20 cc/min (3.3×10⁻⁷ m³/s), respectively for 0.6 hour. The temperature of the reactor was then increased to 400°C over 2 hours. The nitrogen flow was cut back to 10 cc/min (1.7×10⁻⁷ m³/s) and the temperature increased to 410°C. After 1 h, the temperature was adjusted to 280°C. Chlorofluorination of CFC-1213xa began at 280°C with HF, CFC-1213xa, and chlorine vapor co-fed to the reactor at a contact time of 15 seconds. The GC-MS analyses of the reactor effluent at 300°C, 350°C, and 400°C with a molar feed ratio of 20:1:4 are given in Table 2.

EXAMPLE 10

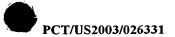
Cobalt-substituted chromium oxide pre-treated with excess ammonium nitrate (Cr/Co 95/5, 21.8 g, 15 mL, -12 to +20 mesh, (1.68 to 0.84 mm)), prepared as described in PREPARATION EXAMPLE 11 was placed in a 5/8" (1.58 cm) diameter Inconel ™ nickel alloy reactor tube heated in a fluidized sand bath. The cobalt-substituted chromium oxide was purged with nitrogen and fluorinated following the general procedure. Chlorofluorination of CFC-1213xa was begun at 300°C with HF, CFC-1213xa, and chlorine vapor co-fed to the reactor in a molar ratio of 20:1:4 with a contact time of 15 seconds. The GC-MS analyses of the reactor effluent at 300°C and 350°C are given in Table 2.

EXAMPLE 11

Cobalt-substituted chromium oxide (Cr/Co 95/5, 900°C, 27.3 g, 15 mL, -12 to +20 mesh, (1.68 to 0.84 mm)), prepared as described in PREPARATION EXAMPLE 10 was placed in a 5/8" (1.58 cm) diameter Inconel[™] nickel alloy reactor tube heated in a fluidized sand bath. The cobalt chromium oxide was purged with nitrogen and fluorinated following the general procedure. Chlorofluorination of CFC-1213xa began at 300°C with HF, CFC-1213xa, and chlorine vapor co-fed to the reactor at a

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contact time of 15 seconds. The GC-MS analyses of the reactor effluent at 350°C with a molar feed ratio of 20:1:4 is given in Table 2.

EXAMPLE 12

Cobalt-substituted chromium oxide (Cr/Co 90/10, 900°C, 32.26 g, 20 mL, -12 to +20 mesh, (1.68 to 0.84 mm)), prepared as described in 5 PREPARATION EXAMPLE 12 was placed in a 5/8" (1.58 cm) diameter Inconel[™] nickel alloy reactor tube heated in a fluidized sand bath. The cobalt-substituted chromium oxide was heated from 50°C to 246°C in a flow of nitrogen (50 cc/min, 8.3×10⁻⁷ m³/s) over the course of about 1.5 hours. The reactor was purged with nitrogen at 20 cc/min (3.3×10⁻⁷ m³/s) at 174°C for 16 hours. HF and nitrogen were then co-fed to the reactor at flow rates of 50 cc/min (8.3×10⁻⁷ m³/s) each at 175°C for 1.3 hours; during this time there was a noticeable exotherm. HF and nitrogen were then co-fed to the reactor at 80 cc/min (1.3×10⁻⁶ m³/s) and 20 cc/min (3.3×10⁻⁷ m³/s), respectively, as the reactor was heated from 15 175°C to 403°C over 4.1 hours. The HF and nitrogen flow rates were then adjusted to 80 cc/min (1.3×10⁻⁶ m³/s) and 10 cc/min (1.7×10⁻⁷ m³/s), respectively, as the reactor was heated at 403°C to 409°C for an additional 2.3 hours. The HF flow was then ceased and the reactor purged with nitrogen at 300°C. Chlorofluorination of CFC-1213xa began at 300°C 20 with HF, CFC-1213xa, and chlorine vapor co-fed to the reactor at a contact time of 15 seconds. The GC-MS analyses of the reactor effluent at 300°C and 350°C with a molar feed ratio of 20:1:4 are given in Table 2.

EXAMPLE 13

Nickel-substituted chromium oxide (Cr/Ni 98/2 calcined at 400°C, 29.6 g, 20 mL, -12 to +20 mesh, (1.68 to 0.84 mm)), prepared as described in PREPARATION EXAMPLE 15, was placed in a 5/8" (1.58 cm) diameter Inconel[™] nickel alloy reactor tube heated in a fluidized sand bath. The nickel chromium oxide was purged with nitrogen and fluorinated following the general procedure. Chlorofluorination of CFC-1213xa began at 300°C with HF, CFC-1213xa, Cl₂ vapor co-fed to the reactor in a molar ratio of 20:1:4 with a contact time of 15 seconds. GC-MS analyses of the reactor effluent at 300°C, 350°C, and 375°C are given in Table 2.

EXAMPLE 14

Nickel-substituted chromium oxide (Cr/Ni 95/5 calcined at 400°C, 29.2 g, 20 mL, -12 to +20 mesh, (1.68 to 0.84 mm)), prepared as described in PREPARATION EXAMPLE 16, was placed in a 5/8"

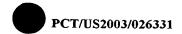
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(1.58 cm) diameter Inconel[™] nickel alloy reactor tube heated in a fluidized sand bath. The nickel chromium oxide was purged with nitrogen and fluorinated following the general procedure. Chlorofluorination of CFC-1213xa began at 300°C with HF, CFC-1213xa, Cl₂ vapor co-fed to the reactor at a contact time of 15 seconds. The GC-MS analyses of the reactor effluent at 300°C, 350°C, and 400°C with molar feed ratios of 20:1:4 and 30:1:2 are given in Table 2.

EXAMPLE 15

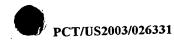
Cobalt- and nickel-substituted chromium oxide (Cr/Co/Ni 95/3/2, 10 26.37g, 19 mL, -12 to +20 mesh, (1.68 to 0.84 mm)), prepared as described in PREPARATION EXAMPLE 17, was placed in a 5/8" (1.58 cm) diameter Inconel[™] nickel alloy reactor tube heated in a fluidized sand bath. The nickel cobalt chromium oxide was purged with nitrogen and fluorinated following the general procedure. Chlorofluorination of CFC-1213xa began at 300°C with HF, CFC-1213xa, Cl₂ vapor co-fed to the reactor at a contact time of 15 seconds. The GC-MS analyses of the reactor effluent at 300°C, 350°C, and 375°C with molar feed ratios of 20:1:4 and 30:1:2 are given in Table 2.

COMPARATIVE EXAMPLE 16

A commercial sample of cobalt chromite (CoCr₂O₄, CAS Reg. No. [12016-69-2], 40.8 g, 20 mL, -12 to +20 mesh, (1.68 to 0.84 mm)),) was pelletized, sieved, and placed in a 5/8" (1.58 cm) diameter Inconel™ nickel alloy reactor tube heated in a fluidized sand bath. The cobalt chromite was purged with nitrogen and fluorinated following the general procedure. Reaction of HF with CFC-1213xa in a molar ratio of 20:1 at 300°C resulted in less than 2% conversion of the 1213xa to a mixture of CFC-1215xc, -1214, and -215aa. Hydrogen fluoride, CFC-1213xa, and chlorine vapor were then co-fed to the reactor with a contact time of 15 seconds. The GC-MS analysis of the reactor effluent at 375°C with a molar feed ratio of 30:1:2 is given in Table 2.

COMPARATIVE EXAMPLE 17

A commercial sample of nickel chromite (NiCr₂O₄, CAS Reg. No. [14721-18-7], 45.0 g, 22 mL, -12 to +20 mesh, (1.68 to 0.84 mm)) was pelletized, sieved, and placed in a 5/8" (1.58 cm) diameter Inconel™ nickel alloy reactor tube heated in a fluidized sand bath. The nickel chromite was purged with nitrogen and fluorinated following the general procedure. Hydrogen fluoride, CFC-1213xa, and chlorine vapor were cofed to the reactor with a contact time of 30 seconds. The GC-MS analysis



of the reactor effluent at 375°C with a molar feed ratio of 20:1:4 is given in Table 2.

Table 2 Chlorofluorination of CFC-1213xa

Reaction Products, GC Area Percent HF/1213/Cl₂ 1215xc | 217ba | 226da | 216aa | 216ba | 215aa | 215bb Temp Ratio Ex. °C No. 0 42.7 19.8 21.6 2.4 11.1 300 0.6 20/1/4 C1 3.0 0 53.0 17.2 0.2 25.2 0.04 375 20/1/4 C1 0 15.3 0.9 40.7 0.2 40.9 0.04 375 30/1/2 C1 0 0.2 67.4 6.4 0.03 24.1 400 0.03 30/1/2 C₁ 0 48.5 16.9 16.2 2.3 14.3 300 0.3 20/1/4 2 17.5 18.0 16.9 34.4 0.9 27.0 350 0.08 20/1/4 2 0 7.7 32.2 14.0 2.0 41.6 0.06 350 30/1/2 2 0 0.1 8.9 0.03 40.8 47.4 0 30/1/2 400 2 0 53.3 2.5 17.1 15.3 9.7 0.6 20/1/4 300 3 0.03 18.6 20.7 37.1 1.1 0.4 20.6 350 20/1/4 3 0 4.6 15.4 1.5 37.9 37.4 350 0.1 30/1/2 3 0 14.6 11.0 45.4 2.5 24.7 0.2 30/1/2 350 зС 0.7 0 9.0 71.5 0.02 17.2 0.03 400 20/1/4 3 0.03 0 4.9 46.4 0.02 46.6 0.06 400 30/1/2 3 30.5 5.2 20.5 16.1 0.4 0.3 8.8 300 4 20/1/4^e 1.6 17.5 26.6 34.9 0.1 14.8 400 0.09 20/1/4 4 24.7 5.9 31.1 20.6 8.0 7.0 300 0.3 5 20/1/4 5.3 18.2 30.8 0.54 25.2 15.5 0.1 20/1/4 350 5 5.9 10.1 28.6 26.8 8.0 22.6 0.2 350 30/1/2 5 18.1 0 31.6 32.4 13.7 0.3 400 0.09 20/1/4 5 0.03 9.9 33.5 30.1 21.6 0.5 0.1 5 30/1/2 400 2.6 44.8 18.4 18.7 11.1 1.3 0.6 20/1/4 300 6 21.0 0 27.0 29.1 20.5 0.7 0.1 350 20/1/4 6 0 9.5 24.7 29.9 1.3 32.6 0.2 350 30/1/2 6 0 21.7 2.6 36.6 0.2 0.04 36.7 400 30/1/2 6 7.1 60.4 9.0 10.0 3.1 8.4 300 0.3 20/1/4 7 0.05 24.7 29.6 19.6 1.8 21.0 0.2 350 20/1/4 7 0.3 25.7 24.0 20.7 1.2 24.3 0.2 350 30/1/4 7 21.4 25.6 28.4 0.4 20.8 400 80.0 20/1/4 7 10.6 0 1.1 33.7 19.6 31.7 0.1 30/1/2 400 7 1.1 50.7 18.5 13.9 2.0 11.3 300 0.9 20/1/4 8 21.2 23.1 32.5 1.0 0.3 19.7 20/1/4 350 8 0 19.3 8.8 29.7 37.5 1.7 0.2 30/1/2 350 8



	HF/1213/C	12	-	Rea	ction Pro	oducts, (GC Area	Percen	t
Ex. No.	Ratio	Temp °C	1215xc	217ba	226da	216aa	216ba	215aa	215bb
9	20/1/4	300	0.7	9.5	0.8	13.3	24.3	42.8	6.2
9	20/1/4	350	0.3	9.8	0.4	35.3	26.6	25.8	0
9	20/1/4	400	0.07	13.1	0.06	58.2	20.1	6.5	0.1
10	20/1/4	300	1.6	11.4	2.0	17.4	15.	50.6	0.1
10	20/1/4	350	0.4	20.4	0.9	34.1	18.6	23.8	0
10	30/1/2	350	0.4	27.6	3.0	42.9	12.2	12.0	0
11 ^f	20/1/4	350	0.2	10.9	0.3	23.3	15.6	21.2	23.9
11 b,c	20/1/4	350	0.7	3.3	0.5	32.1	23.3	35.7	1.0
129	20/1/4	300	0.4	3.6	1.6	18.4	4.8	55.6	10.7
12	20/1/4	350	0.3	9.9	1.1	29.7	17.4	32.6	5.9
13	20/1/4	300	2.2	8.5	3.1	21.6	17.0	46.3	0
13	20/1/4	350	0.2	15.8	0.7	55.6	15.3	11.1	0.09
13	30/1/2	375	0.2	27.4	0.2	58.9	10.4	1.0	0.02
14	20/1/4	300	1.6	9.2	2.4	17.1	22.0	44.3	1.8
14	20/1/4	350	0.4	18.1	1.3	30.1	25.1	22.9	0.2
14	30/1/2	400	0.1	31.1	0.3	41.2	20.6	4.6	0.06
15	20/1/4	300	0.8	12.5	1.9	16.0	18.6	46.3	1.8
15	20/1/4	350	0.2	19.4	1.2	35.5	18.6	23.0	0
15	30/1/2	375	0.2	34.0	1.0	40.8	16.3	5.0	0
C16 ^{d,h}	30/1/2	375	2.1	0.3	0	0.8	0.5	9.7	26.0
C17 ^{b,i}	20/1/4	375	1.5	0	0.5	1.6	6.9	45.5	8.8

- a. Other products formed include 13, 112, 113, 114, 114a, 115, 216cb, 217ca, 218, 225da, 1214, 1225, and 214ab.
- b. Contact time = 30 seconds.
- 5 c. Different catalyst sample prepared by the same procedure.
 - d. Products include 13.2% CFC-1214's.
 - e. Products included 14.1% CFC-214ab and 0.1% unconverted CFC-1213xa.
 - f. Products included 0.4% CFC-214ab.
 - g. Products included 2.7% CFC-214ab.
- h. Products included 18.8% CFC-214ab and 27.1% unconverted CFC-1213xa.
 - i. Products included 3.1% CFC-214ab and 24.9% unconverted CFC-1213xa.
 - j. Products included 6.6% unconverted CFC-1213xa.

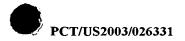
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CLAIMS

What is claimed is:

1. A process for the preparation of 2-chloro-1,1,1,3,3,3-heptafluoropropane, comprising:

(a) contacting a mixture comprising hydrogen fluoride, chlorine, and at least one starting material selected from the group consisting of halopropenes of the formula CX₃CCl=CX₂ and halopropanes of the formula the CX₃CClYCX₃, wherein each X is independently selected from the group consisting of F and Cl, and Y is selected from the group consisting of H, Cl and F, provided that the number of X and Y which are F totals no more than six, with a chlorofluorination catalyst in a reaction zone to produce a product mixture comprising CF₃CClFCF₃, HCl, HF, and underfluorinated halogenated hydrocarbon intermediates;

wherein said chlorofluorination catalyst comprises at least one chromium-containing component selected from (i) a crystalline alpha-chromium oxide where at least 0.05 atom % of the chromium atoms in the alpha-chromium oxide lattice are replaced by nickel, trivalent cobalt or both nickel and trivalent cobalt, provided that no more than 2 atom % of the chromium atoms in the alpha-chromium oxide lattice are replaced by nickel and that the total amount of chromium atoms in the alpha-chromium oxide lattice that are replaced by nickel and trivalent cobalt is no more than 6 atom %, and (ii) a fluorinated crystalline oxide of (i).

- 2. The process of Claim 1 further comprising
 - (b) separating the product of step (a) to recover CF₃CCIFCF₃ as a product and to obtain underfluorinated halogenated hydrocarbon intermediates; and
 - (c) returning underfluorinated halogenated hydrocarbon intermediates obtained in step (b) back to the step (a) reaction zone.
- 3. A process for the manufacture of a mixture of CF₃CHFCF₃ and CF₂=CFCF₃ by reacting a starting mixture comprising CF₃CCIFCF₃ and hydrogen in the vapor phase at an elevated temperature, optionally in the presence of a hydrogenation catalyst, characterized by preparing the CF₃CCIFCF₃ by the process of Claim 1.

INTERNATION SEARCH REPORT

Interna Application No PCT/L B/26331

A. CLASSIFICATION OF SUBJECT MATTER IPC 7 C07C17/20 C07C17/21 C07C17/23 C07C19/10 C07C21/18 B01J23/86 According to International Patent Classification (IPC) or to both national classification and IPC **B. FIELDS SEARCHED** Minimum documentation searched (classification system followed by classification symbols) C07C IPC 7 B01J Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Electronic data base consulted during the international search (name of data base and, where practical, search terms used) EPO-Internal, BEILSTEIN Data, WPI Data, CHEM ABS Data C. DOCUMENTS CONSIDERED TO BE RELEVANT Relevant to claim No. Citation of document, with indication, where appropriate, of the relevant passages 1 - 3EP 0 434 409 A (DU PONT) Α 26 June 1991 (1991-06-26) cited in the application the whole document 1-3 WO 99 51553 A (MANOGUE WILLIAM H ; DU PONT Α (US); NAPPA MARIO JOSEPH (US); SIEVERT) 14 October 1999 (1999-10-14) cited in the application the whole document Further documents are listed in the continuation of box C. Patent family members are listed in annex. Special categories of cited documents: *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the A document defining the general state of the art which is not considered to be of particular relevance invention earlier document but published on or after the international "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to filing date involve an inventive step when the document is taken alone *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) 'Y' document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art. O document referring to an oral disclosure, use, exhibition or other means document published prior to the international filing date but later than the priority date claimed "&" document member of the same patent family Date of mailing of the international search report Date of the actual completion of the international search 9 January 2004 15/01/2004 Name and mailing address of the ISA Authorized officer European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Goetz, G Fax: (+31-70) 340-3016

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